THE
BIOLOGICAL BULLETIN

PUBLISHED BY THE MARINE BIOLOGICAL LABORATORY

OXYGEN CONSUMPTION OF AN ASTEROID AND AN ECHINOID FROM THE ANTARCTIC

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A number of measurements of oxygen consumption by temperate and warm-water echinoderms are now available (Steen, 1965 ; Farmanfarmaian, 1966 ; Giese, Farmanfarmaian, Hilden and Doezema, 1966 ; Giese, 1967 ; Johansen and Vadas, 1967 ; Lewis, 1967 ; McPherson, 1968 ; Johansen and Peterson, 1971 ; Webster, in preparation ; Webster and Giese, in preparation), but no studies have been recorded for polar forms. It is of great interest, therefore, to compare oxygen consumption of echinoderms living at near the freezing point of water to those living at temperatures of 10 to 25° C in temperate and tropical waters. An opportunity presented itself to make such studies on echinoderms from the antarctic waters off McMurdo Station, where the sea temperature is almost constantly −1.8° C.

The investigation described here deals with aspects of the respiratory physiology of the echinoid *Sterechinus neumayeri* and the asteroid *Odontaster validus,* with special emphasis on the contribution of the body wall to the oxygen consumption of the intact organism. The effects of small temperature increases on the oxygen consumption of these species were also examined.

MATERIALS AND METHODS

Odontaster and *Sterechinus* are conspicuous components of the shallow marine benthic community in the antarctic, especially near McMurdo Station (Dayton, Robillard and Paine, 1970). Both were collected by hand while diving on SCUBA near Cape Armitage, McMurdo Sound, Antarctica (79° S, 166° E) during October and November 1972. All animals were obtained in less than 20 meters of water. Following collection, the specimens were transported in insulated containers to the Eklund Biology Laboratory at McMurdo Station, where they were placed in refrigerated seawater aquaria held at −1.8° C. While the animals were not fed, diatoms and other detrital material were probably available in the aquaria.

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Body components*	Sterechinus	Odontaster
Body wall	28.9 ± 2.8	42.2 ± 5.4
Gonad M	20.0 ± 10.1	4.6 ± 3.2†
F	31.0 ± 14.4	—
Lantern	4.2 ± 0.9	—
Caeca	—	20.3 ± 2.5
Gut	2.9 ± 1.0	2.7 ± 0.7
Fluid M	44.1 ± 10.9	29.4 ± 9.0†
F	32.5 ± 13.4	—
Wet weight g	71.6 ± 10.1	18.5 ± 5.9

* Averages for 15 specimens plus or minus one standard deviation; M = male; F = female. Values are given in percent of wet body weight.

† Sex not differentiated.

Oxygen consumption rates were determined for individual animals in closed respirometers with Clark-type oxygen electrodes. The respirometers consisted of glass containers surrounded by plexiglas cooling-jackets. Coolant (50% ethanol) was circulated through the cooling-jackets with a Forma-Temp Jr. regrigerated water bath. The experimental temperature was maintained within ±0.1° C. The respirometers were stirred with slowly revolving magnetic stirring bars, separated from the animals by plexiglas grids. All experiments were carried out in fresh seawater passed through #1 Whatman filter paper. Oxygen consumption was continuously monitored after the methods of Childress (1968). Each experiment lasted 4 to 8 hours, during which the partial pressure of oxygen fell from the maximal value to the minimal at which respiration could be measured.

The rate of oxygen consumption was determined for each species at three temperatures. For acclimation to temperatures above ambient (−1.8° C), the temperature of the aquarium in which the animals were held was raised at approximately 1° C every 24 hours. The animals were held at the new temperature no less than three days before experiments were begun.

As a control on microbial respiration, the animal was removed from the chamber at the end of each experiment, air-saturated seawater was added to replace its volume, and the rate of oxygen consumption by the wash water in the chamber was again measured for at least two hours. These control rates were negligible except at 3° C. In all cases, control rates of wash water were independent of oxygen tension and constant with respect to time. Where a control rate was measured, it was subtracted from the respiratory rate measured with the animal in the chamber to obtain the net respiration of the animal.

After each experiment, the animal was removed from the respirometer and returned to the seawater aquarium for no less than two hours. Following this, the animal was weighed and opened, and the gonads, gut, perivisceral fluid, caeca (stars), and lantern (urchins) were removed and weighed. The body wall was then placed in the respirometer, and oxygen consumption was determined as for the whole animal. Oxygen consumption by the wash water was determined for these experiments also.

The wet-weight measurements of whole animals and their component parts are approximations. Both species studied tend to lose fluid for a long period after
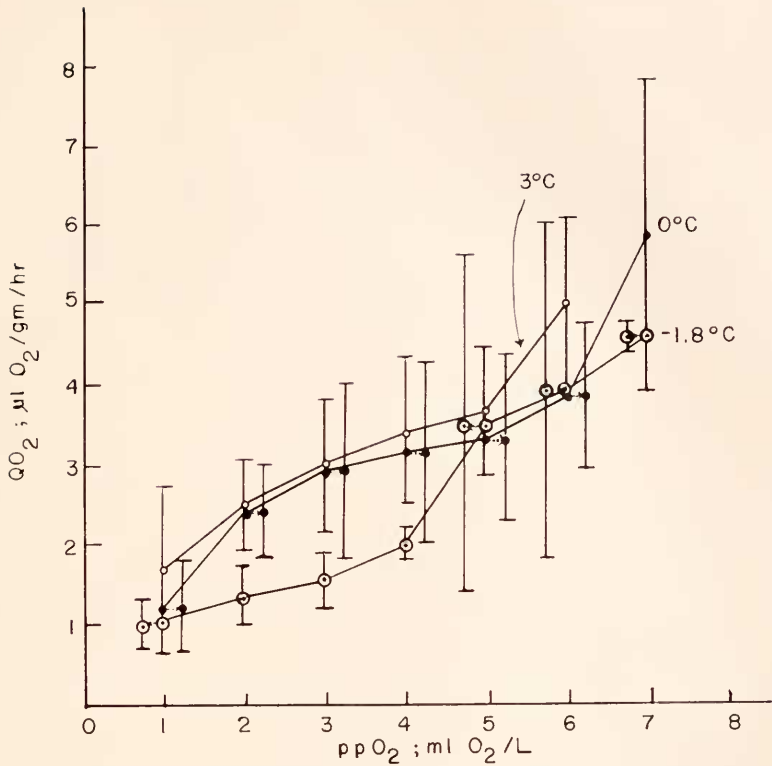
FIGURE 1. Oxygen consumption (QO_2, ordinate) in $\mu lO_2/g/hr$ for the echinoid *Sterechinus neumayeri* at $-1.8°$ C, $0°$ C, and $3°$ C at different partial pressures of oxygen (ppO_2, abscissa) in mlO_2/l. Experiments lasted 4 to 8 hr in Figures 1 to 4. The bars about the means are single standard deviation units. The bars in Figures 1–4 for $-1.8°$ C are offset to the left to avoid confusion.

removal from the water (Pearse, 1965). To standardize the weights used, the organisms were removed from the seawater and allowed to drain for five minutes on paper toweling before weighing, in accordance with the arbitrary choice commonly employed for echinoderms (Giese, 1966).

RESULTS

The measurements of body components of *Sterechinus* and *Odontaster* are summarized in Table I. The body wall constitutes 29% of the total mass of *Sterechinus* and 42% of *Odontaster*. These values must be considered only an order of magnitude, however, since, as noted above, these species lose water constantly and wet weights are approximations. The high gonad index, about 20% in male and 31% in female *Sterechinus* indicates that the sea urchins had not yet spawned-out for the year. Spawning usually occurs in this species during October and November (Pearse and Giese, 1966). Several specimens did, in fact, spawn during experiments (these experiments were discarded). The low gonad index of *Odontaster*

corresponds to the index previously found at this time of year (Pearse, 1965). The caecum of *Odontaster* makes up for the bulk lost with spawn-out in the gonad.

Figures 1–4 show the rates of oxygen consumption of whole and eviscerated *Sterechinus* and *Odontaster* at three temperatures under conditions of falling ppO₂. Since the QO₂ was measured in a "closed" system, the falling ppO₂ is due to the respiration of the animal. The proportional decrease in QO₂ with decreasing ppO₂ is as expected, since echinoderms are generally considered to be "conformers" (Farmanfarmaian, 1966).

The mean per cent of saturation of dissolved oxygen in the water near McMurdo Station is 69%, with a range of only 6% (Tressler, 1964). Since the animals
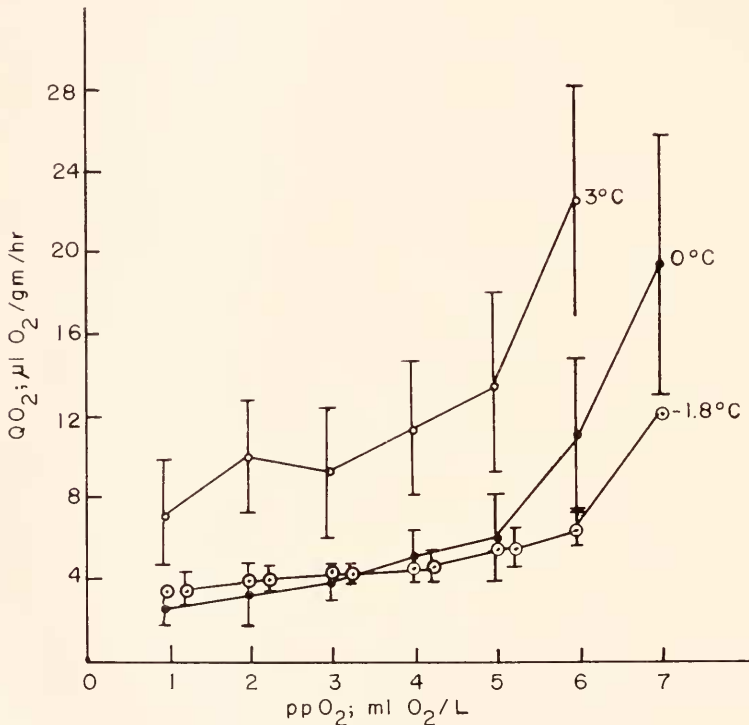

FIGURE 2. Oxygen consumption (QO₂, ordinate) in μlO₂/g/hr for the body wall of the echinoid *Sterechinus neumayeri* at −1.8° C, 0° C, and 3° C at different partial pressures of oxygen (ppO₂, abscissa) in mlO₂/l. The bars about the means are single standard deviation units.

studied occur at this oxygen level, the mean QO₂ for each was calculated from the data in Figures 1–4 at the corresponding ppO₂. For whole *Sterechinus,* the mean QO₂ at −1.8° C is 3.5 ± 2.1 μlO₂/g hr; for the body wall, 5.6 ± 0.9 μlO₂/g/hr. The mean oxygen consumption for the asteroid at −1.8° C is 4.9 ± 1.5 μlO₂/g/hr; for the body wall, 9.6 ± 2.0 μlO₂/g/hr.

There was no significant increase in QO₂ with rise in temperature within the range tested (−1.8° C to 3° C) for either whole *Sterechinus* or *Odontaster*. For

the body wall of the urchin, the QO_2 at 3° C was higher than at either 0° C or −1.8° C, the rates at the latter temperatures not differing significantly (Fig. 2). It was not possible to extend this study to a wider range of temperatures, because below −1.8° C the medium froze and at 5° C the animals became flaccid and eventually died.

It would be interesting to determine the effect of the reproductive state (*e.g.,* gonad index) upon oxygen consumption in these polar species as has been done for temperate species (Webster and Giese, in preparation). Animals of greatly differing gonad index were not available during the short period of time spent in the Antarctic. However, no significant correlation could be demonstrated between
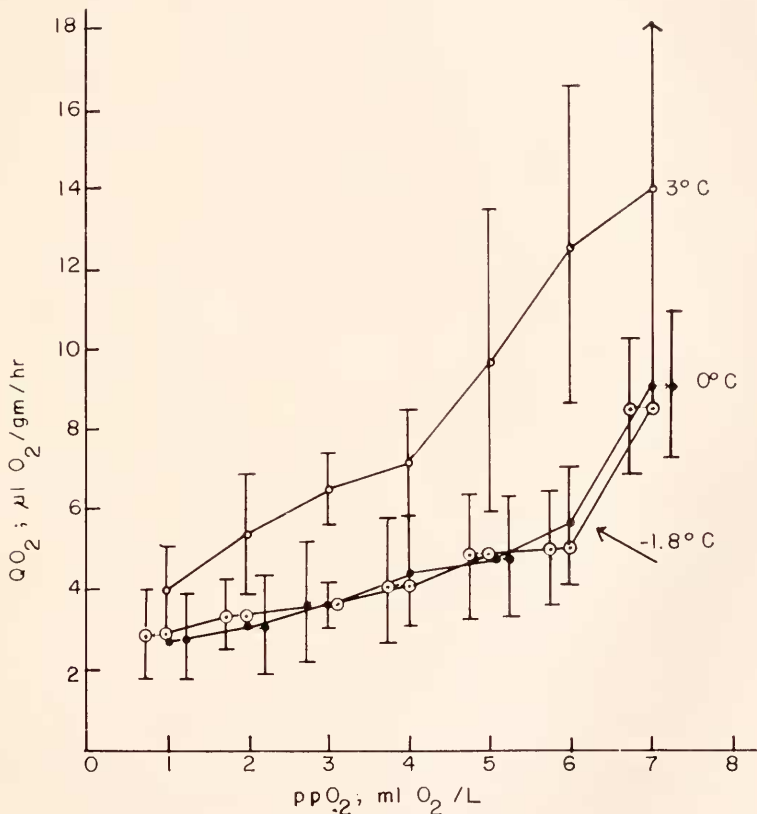

FIGURE 3. Oxygen consumption (QO_2, ordinate) in $\mu lO_2/g/hr$ for the asteroid *Odontaster validus* at −1.8° C, and 3° C at different partial pressures of oxygen (ppO_2, abscissa) in $mlO_2/$ l. The bars about the means are single standard deviation units.

the rate of oxygen consumption and the gonad index by the coefficient of correlation test. No significant correlation between the rate of oxygen consumption and the gonad index was observed in the purple sea urchin *Strongylocentrotus purpuratus,* for which data are available spanning the entire reproductive cycle (Webster and Giese, in preparation).

Discussion

The mean rate of oxygen consumption, QO_2, of the antarctic sea urchin *Sterechinus* determined in the present study compares with the QO_2 of a number of sea urchins of temperate waters, for example *Strongylocentrotus franciscanus* of the west coast of North America at about 13° C, *Allocentrotus fragillis* from deeper waters off the same coast at 8° C, and two sea urchins, *Evechinus chloroticus* and *Goniocidaris umbraculum,* from New Zealand at 13° C. The QO_2 for *Sterechinus* is considerably less than that for various tropical sea urchins: *Lytechinus anamesus* from Punta Banda, Mexico at 16° C, *Echinometra mathaei* from Savai's,
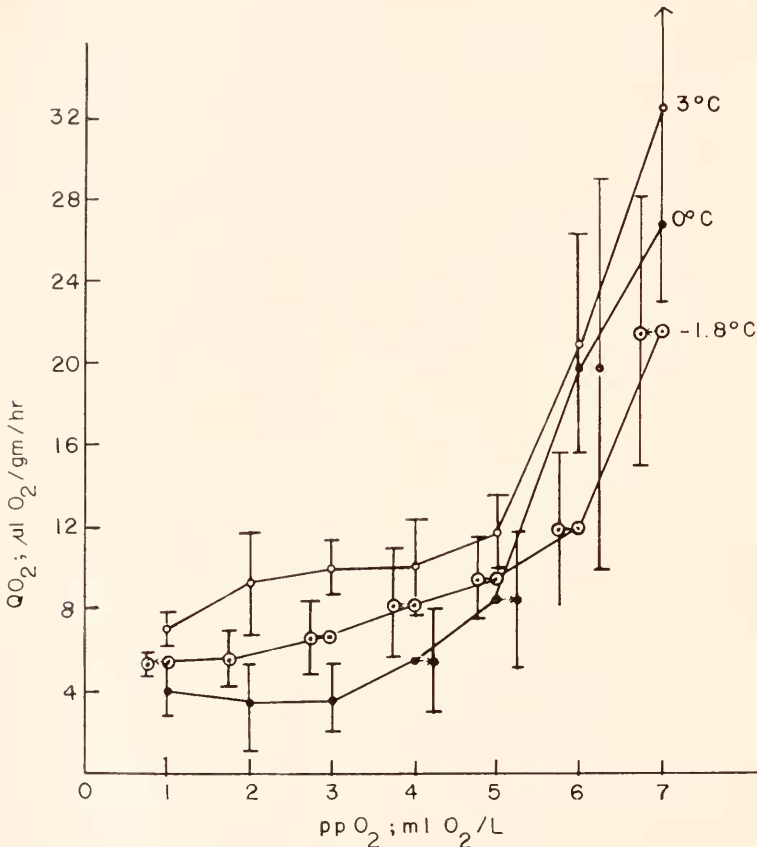

FIGURE 4. Oxygen consumption (QO_2, ordinate) in $\mu lO_2/g/hr$ for the body wall of the asteroid *Odontaster validus* at −1.8° C, 0° C, and 3° C at different partial pressures of oxygen (ppO_2, abscissa) in mlO_2/l. The bars about the means are single standard deviation units.

Western Samoa at 23° C, *E. lucunter* and *Tripneustes esculentus* from St. John, U. S. Virgin Islands at 28° C (Webster, in preparation).

That the body wall of *Sterechinus* is probably the main consumer of oxygen during respiration in the echinoid is not surprising in view of its prominence in the body and its biological nature (Table I). In all echinoderms, the body wall

is not strictly a skeleton, but contains many cells, stores of nutrient, and some muscle and nerve. That the body wall should have a QO_2 higher than the whole body is explainable in terms of the availability of oxygen to the internal tissues of the whole animal. In the intact purple sea urchin, the oxygen in seawater impinging on the outer surface is quickly used, so that the perivisceral fluid within has only one-half to one-fourth (or less) the oxygen at the surface (Webster and Giese, in preparation). The inner surface of the body wall of the echinoid is therefore bathed in fluid with a considerably attenuated oxygen supply. When the body wall is dissected out and the internal side is exposed to the same oxygen levels as the external side, the whole body wall receives much more oxygen than previously, and its QO_2 rises accordingly.

Much of what has been said of *Sterechinus* applies equally well to *Odontaster*. The whole body QO_2 of *Odontaster* is of the same order of magnitude as the QO_2 of *Zoroaster evermanni* and *Dermasterias imbricata* at 13° C, both from Monterey Bay, and *Pentagonaster pulcrellus* at 13° C from New Zealand. The QO_2 of *Odontaster* is from $\frac{1}{2}$ to $\frac{1}{5}$ that of a series of six asteroids from Monterey Bay measured at 13° C (Webster, in preparation). We found no data on tropical asteroids with which to make comparisons. In *Odontaster* the body wall has a higher QO_2 than the whole body, probably for the same reason as in *Sterechinus*.

The conclusion we have drawn from the data presented in Figures 1 and 3 is that temperatures up to 4.8° C above ambient have no significant effect on the rate of oxygen consumption of acclimated *Sterechinus* and *Odontaster*. It is possible, of course, that such an effect has been masked by the variability of individual experiments. The relatively small difference between the mean QO_2 at each temperatures suggests, however, that, even if this were the case, the effect of temperature on the QO_2 in these species is slight. Therefore, over the range of temperatures −1.8° C to 3° C, the temperature coefficient appears to be close to unity. Over this temperature range the metabolism of these antarctic echinoderms appears to be temperature-insensitive, suggesting metabolic rate compensation. Temperature coefficients for thermal acclimation over a wide range of temperature in the purple sea urchin suggest enzymatic adaptation (Farmanfarmaian and Giese, 1963). A study of the enzymatic basis of thermal acclimation on representative echinoderms from tropical, temperate and polar environments, similar to that made on other animals as recently reviewed (Hochachka and Somero, 1973), would therefore be of great interest.

Summary

The mean oxygen consumption, QO_2, in $\mu lO_2/g/hr$ at −1.8° C (ambient temperature), of the antarctic echinoid *Sterechinus neumayeri* and the antarctic asteroid

Odontaster validus, determined with an oxygen electrode, were recorded as follows: *S. neumayeri* (whole body) 3.5 ± 2.1, (body wall) 5.6 ± 0.9; and *O. validus* (whole body) 4.9 ± 1.5, (body wall) 9.6 ± 2.0. The oxygen consumption fell with the decline in partial pressure of oxygen as the oxygen was used by the organisms. Small increases in temperature, from $-1.8°$ C to $3°$ C, had no significant effect on the QO_2 of whole animals, and at $3°$ C only a small effect on the QO_2 of the body wall. Comparisons indicate that some temperate species have QO_2 values in the same range as the antarctic species. Tropical species cited, however, consume oxygen at a higher rate than the antarctic species.

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